TITLE OF THE INVENTION

ZOOM LENS AND OPTICAL APPARATUS USING THE SAME

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a zoom lens and an optical apparatus using the same and, more particularly, to a zoom lens utilizing the rear-focus method and having a high range with a relatively small number of constituent lenses, suited to be used in video cameras, film cameras and broadcasting cameras, and an optical apparatus using the same.

Description of Related Art

For ~~the~~ a zoom lens to be used in ~~the~~ a photographic camera, a video camera or like optical apparatus, the use of a lens unit other than the front or first lens unit in focusing, or the so-called "rear-focus" method, has been previously proposed in many examples. This is because the rear-focus method admits a lens unit of relatively small size and light weight to move during focusing. Therefore, the driving torque ~~is saved~~ can be weak and, nonetheless, fast focus adjustment can be effected, so that the rear-focus method has an advantage for good adaptation to the auto-focus system.

Such a rear-focus type of zoom lens is disclosed in, for example, Japanese laid-Open Patent Application No. Sho 63-44614, which comprises, in order from an object side, a first lens unit of positive refractive power, a second lens unit of negative refractive power axially movable for varying the focal length, a third

lens unit of negative refractive power axially movable for compensating for the shift of the image plane with variation of the focal length and a fourth lens unit of positive refractive power, totaling four lens units. In this so-called "4-unit" zoom lens, the third lens unit is made movable to effect focusing. However, such an arrangement must assure creation of a large space in which to move the third lens unit. So, the total length of the entire lens system tends to increase greatly.

Japanese Laid-Open Patent Application No. Sho 63-278013, too, discloses a 4-unit zoom lens comprising a first lens unit of positive refractive power, a second lens unit of negative refractive power, a third lens unit of negative refractive power and a fourth lens unit of positive refractive power, wherein zooming is performed by the second lens unit and compensation for the image shift and focusing are performed by the fourth lens unit. In the zoom lens configuration that has made the third lens unit negative in refractive power, however, because the diverging rays of light from the second lens unit are further diverged by the third lens unit, the diameter of the fourth lens unit becomes larger, ~~giving a cause of~~ causing the increasing the bulk and size of the entire lens system. Moreover, the range of variation of aberrations due to focusing tends to ever more widen.

On the other hand, Japanese Laid-Open Patent Applications No. Sho 62-24213 (corresponding to U.S. Patent No. 4,859,042) and No. Sho 63-247316 propose a

zoom lens comprising, in order from an object side, a first lens unit of positive refractive power, a second lens unit of negative refractive power, a third lens unit of positive refractive power and a fourth lens unit of positive refractive power, totaling four lens units, wherein the second lens unit moves to effect zooming and the fourth lens unit moves to compensate for the image shift with zooming and to effect focusing. Such an arrangement assures minimization of the bulk and size of the entire lens system.

Japanese Laid-Open Patent Application No. Sho 63-29718 discloses a zoom lens comprising, in order from an object side, a first lens unit of positive refractive power, a second lens unit which is constructed with a negative lens, a negative lens and a positive lens, totaling three lenses, whose overall refractive power is negative and which, during zooming, is movable as mainly governing the variation of the focal length, a third lens unit having a positive refractive power and containing an aspheric surface and, after a bit large air separation, a fourth lens unit having a positive refractive power and movable for compensating for the image shift with zooming and for focusing.

Japanese Laid-Open Patent Application No. Hei 5-72472 discloses a zoom lens, using aspheric surfaces, which comprises, in order from an object side, a first lens unit having a positive refractive power and stationary during zooming and focusing, a second lens

unit having a negative refractive power and movable for zooming, a third lens unit of positive refractive power fixed and having a light condensing action and a fourth lens unit of positive refractive power axially movable for keeping the constant position of the image plane against zooming, wherein the second lens unit is constructed with a negative lens of meniscus form, a negative lens of bi-concave form and a positive lens, the third lens unit is constructed with a single lens having one or more aspheric surfaces, and the fourth lens unit is constructed with lenses having one or more aspheric surfaces.

In the above-mentioned references, however, there is not disclosed any zoom lens in which the second lens unit is constructed with four lenses. Further, there is not disclosed any arrangement in which an aspheric surface is contained in the second lens unit.

Meanwhile, U.S. Patent No. 4,299,454 discloses a zoom lens comprising, in order from an object side, a positive first lens unit, a negative second lens unit and a positive rear lens unit, wherein zooming is performed by moving at least two lens units including the negative second lens unit. The negative second lens unit is constructed with, in order from the object side, first and second negative lenses and a positive doublet. However, because the third lens unit is movable, the mechanism therefor results in an increased complexity of structure. U.S. Reissue Patent No. 32,923 discloses a

zoom lens comprising, in order from an object side, a positive first lens unit, a negative second lens unit, a stop, a positive third lens unit and a positive fourth lens unit. The first and fourth lens units are arranged during zooming to move in the same direction, and the stop remains stationary during zooming. Further, the second lens unit contains one cemented lens.

In the two U.S. Patents mentioned above, however, there are no examples suggesting that the third lens unit is constructed with inclusion of a double-aspherical lens and also that any aspheric surface is used in the second lens unit.

Japanese Laid-Open Patent Applications No. Hei 7-270684 and No. Hei 7-318804 disclose a zoom lens comprising, in order from an object side, a first lens unit having a positive refractive power and being fixed, a second lens unit having a negative refractive power and axially movable for varying the focal length, a third lens unit having a positive refractive power and being fixed and a fourth lens unit of positive refractive power axially movable for keeping the constant position of the image plane against zooming and for focusing, wherein the second lens unit is constructed with four single lenses. However, there are disclosed no zoom lenses having a double-aspherical lens in the third lens unit.

Japanese Laid-Open Patent Applications No. Hei 5-060974 discloses a zoom lens comprising, in order from an object side, a first lens unit having a positive

refractive power and being fixed, a second lens unit having a negative refractive power and axially movable for varying the focal length, a third lens unit having a positive refractive power and being fixed and a fourth lens unit of positive refractive power axially movable for keeping the constant position of the image plane against zooming and for focusing, wherein the total length of the entire lens system is shortened. However, there are disclosed no zoom lenses both with the use of four single lenses in the second lens unit and with a double-aspherical lens in the third lens unit.

BRIEF SUMMARY OF THE INVENTION

The present invention is concerned with an unconventional or novel zoom lens configuration which improves the compact form of the entire lens system. An object of the invention is, therefore, to provide a zoom lens of high range, while still permitting the high optical performance to be maintained stable throughout and, moreover, the number of constituent lenses to be reduced so that it takes a simple form, and an optical apparatus using the same.

To attain the above-described object, in accordance with a first aspect of the invention, there is provided a zoom lens which comprises, in order from an object side to an image side, a first lens unit of positive refractive power, a second lens unit of negative refractive power, a third lens unit of positive

refractive power and a fourth lens unit of positive refractive power. Zooming from a wide-angle end to a telephoto end is ~~being~~ effected by moving the second lens unit toward the image side, and shifting of an image plane due to zooming being compensated for by moving the fourth lens unit, wherein the second lens unit consists of four separate single lenses including three negative lenses and one positive lens, and the third lens unit has at least one positive lens both surfaces of which are aspherical.

Further, in accordance with a second aspect of the invention, there is provided a zoom lens which comprises, in order from an object side to an image side, a first lens unit of positive refractive power, a second lens unit of negative refractive power, a third lens unit of positive refractive power and a fourth lens unit of positive refractive power. Zooming from a wide-angle end to a telephoto end is ~~being~~ effected by moving the second lens unit toward the image side, and shifting of an image plane due to zooming being compensated for by moving the fourth lens unit, wherein the second lens unit consists of four single lenses including three negative lenses and one positive lens, and at least one of the four single lenses is an aspherical lens.

Further, in accordance with a third aspect of the invention, there is provided an optical apparatus which comprises a zoom lens according to the first or second aspect of the invention.

The above and further aspects and features of the invention will become apparent from the following detailed description of preferred embodiments thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Fig. 1 is a longitudinal section view of a numerical example 1 of the zoom lens.

Figs. 2A to 2D are graphic representations of the aberrations of the zoom lens of numerical example 1 in the wide-angle end.

Figs. 3A to 3D are graphic representations of the aberrations of the zoom lens of numerical example 1 in a middle focal length position.

Figs. 4A to 4D are graphic representations of the aberrations of the zoom lens of numerical example 1 in the telephoto end.

Fig. 5 is a longitudinal section view of a numerical example 2 of the zoom lens.

Figs. 6A to 6D are graphic representations of the aberrations of the zoom lens of numerical example 2 in the wide-angle end.

Figs. 7A to 7D are graphic representations of the aberrations of the zoom lens of numerical example 2 in a middle focal-length position.

Figs. 8A to 8D are graphic representations of the aberrations of the zoom lens of numerical example 2 in the telephoto end.

Fig. 9 is a longitudinal section view of a numerical example 3 of the zoom lens.

Figs. 10A to 10D are graphic representations of the aberrations of the zoom lens of numerical example 3 in the wide-angle end.

Figs. 11A to 11D are graphic representations of the aberrations of the zoom lens of numerical example 3 in a middle focal-length position.

Figs. 12A to 12D are graphic representations of the aberrations of the zoom lens of numerical example 3 in the telephoto end.

Fig. 13 is a longitudinal section view of a numerical example 4 of the zoom lens.

Figs. 14A1 to 14A4, 14B1 to 14B4 and 14C1 to 14C4 are graphic representations of the aberrations of the zoom lens of numerical example 4 in three different operative positions.

Fig. 15 is a longitudinal section view of a numerical example 5 of the zoom lens.

Figs. 16A1 to 16A4, 16B1 to 16B4 and 16C1 to 16C4 are graphic representations of the aberrations of the zoom lens of numerical example 5 in three different operative positions.

Fig. 17 is a longitudinal section view of a numerical example 6 of the zoom lens.

Figs. 18A1 to 18A4, 18B1 to 18B4 and 18C1 to 18C4 are graphic representations of the aberrations of the zoom lens of numerical example 6 in three different

operative positions.

Fig. 19 is a schematic diagram for explaining an example of application of the zoom lens of each of the numerical examples 1 to 6 to the video camera.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, preferred embodiments of the invention will be described in detail with reference to the drawings.

Fig. 1 in block diagram shows a numerical example 1 of the rear-focus type zoom lens according to a first embodiment of the invention. Figs. 2A to 2D, Figs. 3A to 3D and Figs. 4A to 4D graphically show the aberrations of the zoom lens of numerical example 1 ~~in~~ at the wide-angle end, ~~an~~ at the middle focal length position and at the telephoto end, respectively.

Fig. 5 in block diagram shows a numerical example 2 of the rear-focus type zoom lens according to the first embodiment of the invention. Figs. 6A to 6D, Figs. 7A to 7D and Figs. 8A to 8D graphically show the aberrations of the zoom lens of numerical example 2 in the wide-angle end, ~~an~~ at the middle focal length position and at the telephoto end, respectively.

Fig. 9 in block diagram shows a numerical example 3 of the rear-focus type zoom lens according to the first embodiment of the invention. Figs. 10A to 10D, Figs. 11A to 11D and Figs. 12A to 12D graphically show the aberrations of the zoom lens of numerical example 3

~~in~~ at the wide-angle end, ~~an~~ at the middle focal length position and at the telephoto end, respectively.

Referring to Figs. 1, 5 and 9, the zoom lens comprises, in order from an object side to an image side, a first lens unit L1 of positive refractive power, a second lens unit L2 of negative refractive power, a third lens unit L3 of positive refractive power and a fourth lens unit L4 of positive refractive power. An aperture stop SP is positioned in front of the third lens unit L3. A color separation prism, a face plate and a filter are represented by a glass block G. Reference character IP stands for an image plane in which a CCD or like image pickup element is disposed.

In the numerical examples 1 to 3, during zooming from the wide-angle end to the telephoto end, as indicated by the arrows in Figs. 1, 5 and 9, the second lens unit axially moves toward the image side, while the fourth lens unit axially moves in part or as a whole (in the numerical examples 1 to 3, as a whole) in a locus convex toward the object side to compensate for the shift of the image plane with a variation of the focal length.

For focusing purposes, the fourth lens unit is also made axially movable in part or as a whole (in the numerical examples 1 to 3, as a whole), that is, the rear-focus method is employed. With an infinitely distant object or an object at the minimum distance, during zooming from the wide-angle end to the telephoto end, the fourth lens unit axially moves, while depicting

a locus shown by the solid line curve 4a or dashed line curve 4b, respectively, in Figs. 1, 5 and 9. Incidentally, the first and third lens units remain stationary during zooming and during focusing.

In the numerical examples 1 to 3, the provision for keeping the constant position of the image plane against zooming and the focusing provision both are made in one and the same lens unit, i.e., the fourth lens unit. In particular, as can be seen from the curves 4a and 4b in Figs. 1, 5 and 9, a locus of motion of the fourth lens unit is made convex toward the object side. Such a locus allows the space between the third and fourth lens units to be utilized with an ever higher efficiency, thus advantageously achieving a shortening of the total length of the entire lens system.

In the numerical examples 1 to 3, with the setting in, for example, the telephoto end, during focusing from infinity to the minimum object distance, the fourth lens unit moves forward as indicated by a straight line 4c in Figs. 1, 5 and 9.

It should now be pointed out that the most characteristic features in the first embodiment are that the second lens unit L2 is constructed with three negative lenses and one positive lens, totaling four separate single lenses and further that, among the surfaces constituting the third lens unit L3, both of the surfaces of at least one positive lens are made aspherical.

In more detail, for the zoom lens of such a configuration as in the first embodiment, the second lens unit L2 that contributes to a large variation of the focal length is made up from such a number of constituent lenses in such an arrangement as described above. The shares of the power the individual lenses take each are thus reduced to thereby assure much lowering of the Petzval sum. Despite the high zoom ratio, therefore, the variation of the field curvature with zooming is minimized. Further, since the second lens unit produces a diverging light beam, because the third lens unit L3 gets so large a diameter as to admit of that light beam, one or more double-aspherical positive lenses are used in the third lens unit, thus assuring improvements of even the level of optical performance. Also, this obviates the necessity of using the aspheric surface in the fourth lens unit, thereby producing an advantage in production cost. In the numerical examples 1 to 3, the asphere is used in both surfaces of a positive lens closest to the object side constituting part of the third lens unit L3.

For the numerical examples 1 to 3, the rules of lens design are set forth as above to obtain a high optical performance throughout the entire zooming range and throughout the entire focusing range.

The zoom lens according to the first embodiment can be realized by satisfying the features described above. To maintain good stability of the optical performance with the zoom ratio kept so ~~much~~ high, it is

preferable to satisfy at least one of the following features or conditions.

(a) The second lens unit L2 is constructed with, in order from an object side to an image side, a negative first lens having a concave surface of larger curvature facing the image side than that of an opposite surface thereof, a bi-concave negative second lens, a positive third lens having a convex surface of larger curvature facing the object side than that of an opposite surface thereof, and a bi-concave negative fourth lens.

With the use of the zoom type as in the first embodiment, in order to increase the zoom ratio, the second lens unit L2 that contributes greatly to the function of varying the focal length must be necessarily made either larger in the total zooming movement, or shorter in ~~the~~ focal length. The former method invites an increase of the size of the zoom lens, so that it is not favorable. The latter method, although not causing the size to increase, puts the second lens unit L2 ~~in suffering~~ under a larger strain of varying the focal length, so that it becomes difficult to maintain good stability of ~~the~~ optical performance. Then, the second lens unit L2 is made up in such a manner as described above, producing ~~an~~ the advantage of preventing the size of the entire lens system from increasing, while the optical performance, too, is maintained ~~in~~ with good stability. Particularly as far as the second lens unit L2 is concerned, chromatic aberrations are corrected well by arranging the negative

lens, the negative lens, the positive lens and the negative lens in this order from the object side, or by making a nearly symmetric power arrangement. That is, the principal point is achromatized well.

(b) In the third lens unit L3, the double aspheres for the positive lens are applied to the first lens, when counted from the object side. This makes it possible to correct aberrations ever more effectively. Particularly ~~for~~ at the wide-angle end, the on-axial spherical aberration is corrected well. In this respect, it is desired to form the aspheric surface to such a shape that the positive refractive power becomes progressively weaker toward the margin thereof.

It has been known in the prior art to use one aspheric surface in the third lens unit. The ~~limitation~~ limiting of the number of aspheric surfaces to one, however, has come and is coming in ever increasing difficulties of sufficiently improving the correction of aberrations and the compact form in the zoom lens configuration of the first embodiment. In other words, to further reduce the bulk of the entire lens system, it is important that the light beam decreases in diameter sufficiently as it passes through the third lens unit. What enters the third lens unit is the diverging rays of light from the second lens unit. To let them emerge in a converging light beam, therefore, as a rule, the third lens unit has borne a strong refractive power.

On this account, the first embodiment ~~is to form~~ forms

the positive lens of the third lens unit to a double-aspherical shape, thereby making it possible to reduce the diameter of the light beam in such a manner as to maintain ~~keep hold of~~ a good state of aberrations. Owing to this, the separation between the third and fourth lens units can also be further reduced to decrease the size of the entire lens system. The improvements of the compact form are thus achieved. In particular, as the diverging rays are incident on the front surface of the double-aspherical lens and then refracted by that surface, the rays incident on the rear surface are made convergent. This allows the aberrations to be corrected well.

(c) The focal length f2 of the second lens unit lies within the following range:

$$0.24 < |f2/fA| < 0.33 \quad \ldots (1)$$

where $\mathbf{fA} = \sqrt{\mathbf{fw \cdot ft}}$

wherein fw and ft are focal lengths at ~~in~~ the wide-angle end and the telephoto end of the entire lens system, respectively.

The above condition (1) is a condition for making appropriate the focal length (in other words, refractive power) of the second lens unit. When the upper limit of the condition (1) is exceeded, as this means that the focal length of the second lens unit is too long, the aberrations are favorably corrected, but the total zooming movement of the second lens unit must be increased to obtain the desired zoom ratio, causing the size of the entire lens system to increase

objectionably. Conversely, when the lower limit is exceeded, the Petzval sum increases in the negative direction, causing the image plane to decline. So, it becomes difficult to keep hold of good optical performance.

(d) For the second lens unit, the mean Abbe number νp of materials of positive lenses which constitute the second lens unit and the mean Abbe number νn of materials of negative lenses which constitute the second lens unit lie within the respective following ranges:

$$36 < \nu n < 65 \quad \ldots (2)$$

$$20 < \nu p < 35 \quad \ldots (3)$$

The above conditions (2) and (3) are provided for correcting well the chromatic aberrations the second lens unit produces. As mentioned in the foregoing, the second lens unit contributes to a large variation of the focal length. Therefore, the aberrations the second lens unit produces must be corrected well. Particularly for the zoom lens whose zoom ratio is as high as 22 or more, it is important to correct chromatic aberrations well, too. When the upper limit of the condition (2) is exceeded, over-correction of longitudinal chromatic aberration results. Conversely, when the lower limit is exceeded, under-correction of longitudinal chromatic aberration results. ~~In the~~ Under condition (3), the phenomena to occur are reversed to those of the condition (2). In either case, when the upper or lower limit is exceeded, the chromatic aberrations are also hardly corrected well.

(e) To correct aberrations, the mean refractive index Nn of materials of negative lenses which constitute the second lens unit lies within the following range:

$$1.70 < Nn < 1.95 \quad \ldots (4)$$

The above condition (4), which correlates with the condition (1), is a condition for preventing the Petzval sum from deteriorating, by using high-refractive-index glasses in the negative lenses. When the limits are exceeded, the curvature of field ~~comes to~~ deteriorates

(f) Letting the radius of curvature of the i-th lens surface, when counted from the object side, in the second lens unit be denoted by R2i, it is preferable to satisfy at least one of the following conditions:

$$0.82 < |R22/f2| < 1.07 \quad \ldots (5)$$

$$1.66 < |R24/R25| < 4.00 \quad \ldots (6)$$

$$1.00 < |R26/R27| < 1.46 \quad \ldots (7)$$

The above conditions (5) to (7) are provided for correcting mainly spherical aberration, coma, astigmatism and field curvature in good balance.

When the upper limit of the condition (5) is exceeded, coma becomes large. Conversely, when the lower limit is exceeded, the image plane comes to bend concave toward the object side. So, these violations are objectionable.

The condition (6) is provided for correcting the various aberrations by cancellation between each other's surfaces. When the upper limit of the condition (6) is

exceeded, under-correction of spherical aberration results. So, the violation is objectionable. Conversely, when the lower limit is exceeded, the inward coma increases objectionably.

When the upper limit of condition (7) is exceeded, spherical aberration is objectionably over-corrected. Conversely, when the lower limit is exceeded, barrel-type distortion in the wide-angle end increases objectionably.

On the conditions (5) to (7), satisfaction of any one of the conditions gives the respective individual effect and result. However, needless to say here, simultaneous satisfaction of all the conditions (5) to (7) is desired from the viewpoint of the aberration correction.

(g) The focal length f3 of the third lens unit lies within the following range:

$$0.86 < |f3/fA| < 1.09 \quad \ldots (8)$$

The above condition (8) is a condition for making appropriate the focal length (in other words, power) of the third lens unit. When the focal length of the third lens unit is longer than the upper limit of the condition (8), the strain of the third lens unit on variation of the focal length becomes lighter, so that it is favorable for correcting aberrations. However, the strain ~~of~~ on the fourth lens unit ~~on variation of~~ to vary the focal length becomes heavy. So, it becomes necessary to increase the number of lens elements in the fourth lens

unit and put an aspherical lens or lenses therein. Therefore, it becomes difficult to improve the compact form. Conversely, when the lower limit is exceeded, as this means that the strain ~~of~~ on the third lens unit ~~on~~ to ~~variation of~~ vary the focal length is too heavy, the optical performance, especially ~~in~~ with respect to spherical aberration, detracts from the good level. So, the violation is objectionable.

(h) The magnification β4T of the fourth lens unit ~~in~~ at the telephoto end with an object at infinity lies within the following range:

$$0.40 < \beta 4T < 0.55 \quad \ldots (9)$$

This factor relates to the focal length of the fourth lens unit. When the magnification of the fourth lens unit is higher than the upper limit of the condition (9), the amount of movement of the fourth lens unit becomes large, hindering the size from being minimized. Conversely, when the lower limit is exceeded, the back focal distance increases objectionably.

Next, three numerical examples 1 to 3 of the first embodiment are shown in detail. In the numerical data for the examples 1 to 3, Ri is the radius of curvature of the i-th lens surface, when counted from the object side, Di is the axial separation (lens thickness or air space) between the i-th and (i+1)st surfaces, and Ni and νi are respectively the refractive index and Abbe number of the material of the i-th lens element.

The shape of an aspheric surface is expressed in

the coordinates with an X axis in the direction of an optical axis and an H axis in the direction perpendicular to the optical axis, the direction in which light advances being taken as positive, by the following equation:

$$X = \frac{(1/R)H^2}{1+\sqrt{1-(1+K)(H/R)^2}} + BH^4 + CH^6 + DH^8 + EH^{10} + FH^{12}$$

where R is the radius of the osculating sphere, and K, B, C, D, E and F are the aspheric coefficients.

Also, it is to be noted that the notation of "e-Z", for example, means "10^{-Z}".

The values of the factors in the above-described conditions (1) to (9) for the numerical examples 1 to 3 are listed in Table-1.

Numerical Example 1:

f= 1~22.30 Fno= 1.65~3.91 2ω= 57.6°~2.8°

R 1= 11.212	D 1= 0.32	N 1= 1.846660	ν 1= 23.8
R 3= 6.058	D 2= 1.22	N 2= 1.603112	ν 2= 60.6
R 3= -82.529	D 3= 0.05		
R 4= 5.587	D 4= 0.68	N 3= 1.696797	ν 3= 55.5
R 5= 14.317	D 5= Variable		
R 6= 7.675	D 6= 0.20	N 4= 1.834000	ν 4= 37.2
R 7= 1.241	D 7= 0.66		
R 8= -4.048	D 8= 0.17	N 5= 1.834807	ν 5= 42.7
R 9= 6.949	D 9= 0.07		
R10= 2.501	D10= 0.67	N 6= 1.846660	ν 6= 23.8

R11= -3.408	D11= 0.04		
R12= -2.782	D12= 0.17	N 7= 1.804000	ν 7= 46.6
R13= 6.600	D13= Variable		
R14= Stop	D14= 0.15		
R15*= 2.129	D15= 1.05	N 8= 1.583126	ν 8= 59.4
R16*= -6.481	D16= 0.05		
R17= 3.123	D17= 0.20	N 9= 1.846660	ν 9= 23.8
R18= 1.807	D18= Variable		
R19= 3.092	D19= 0.68	N10= 1.516330	ν10= 64.1
R20= -2.037	D20= 0.17	N11= 1.805181	ν11= 25.4
R21= -3.768	D21= Variable		
R22= ∞	D22= 0.81	N12= 1.516330	ν12= 64.2
R23= ∞			

*) Aspheric Surface

Variable Separation	Focal Length		
	1.00	8.95	22.30
D 5	0.17	4.79	5.67
D13	5.95	1.33	0.45
D18	2.85	1.17	3.27
D21	0.73	2.42	0.32

Aspheric Coefficients:

R15:	K=-2.95062e+00	B= 2.77965e-02	C=-4.26812e-03
	D=-3.54540e-04	E= 1.02158e-03	F=-3.32079e-04
R16:	K=-1.61171e+01	B= 4.17705e-03	C=-2.13701e-03
	D= 2.19892e-03	E=-8.75276e-04	F= 2.08033e-05

Numerical Example 2:

f= 1~24.54 Fno= 1.65~4.02 2ω= 57.9°~2.6°

R 1= 11.033	D 1= 0.32	N 1= 1.846660	ν 1= 23.8
R 2= 6.233	D 2= 1.34	N 2= 1.603112	ν 2= 60.6
R 3= -77.014	D 3= 0.05		
R 4= 5.701	D 4= 0.69	N 3= 1.638539	ν 3= 55.4
R 5= 13.327	D 5= Variable		
R 6= 6.654	D 6= 0.20	N 4= 1.834000	ν 4= 37.2
R 7= 1.222	D 7= 0.69		
R 8= -3.818	D 8= 0.17	N 5= 1.834807	ν 5= 42.7
R 9= 9.572	D 9= 0.12		
R10= 2.639	D10= 0.64	N 6= 1.846660	ν 6= 23.8
R11= -3.900	D11= 0.01		
R12= -3.497	D12= 0.17	N 7= 1.804000	ν 7= 46.6
R13= 5.438	D13= Variable		
R14= Stop	D14= 0.15		
R15*= 2.264	D15= 1.04	N 8= 1.583126	ν 8= 59.4
R16*= -6.688	D16= 0.05		
R17= 3.418	D17= 0.20	N 9= 1.846660	ν 9= 23.8
R18= 1.995	D18= Variable		
R19= 3.275	D19= 0.74	N10= 1.516330	ν10= 64.1
R20= -1.950	D20= 0.17	N11= 1.805181	ν11= 25.4
R21= -3.563	D21= Variable		
R22= ∞	D22= 0.81	N12= 1.516330	ν12= 64.2
R23= ∞			

*) Aspheric Surface

Variable Separation	Focal Length		
	1.00	9.49	24.54
D 5	0.21	5.27	6.23
D13	6.25	1.20	0.23
D18	3.12	1.23	3.48
D21	0.74	2.62	0.37

Aspheric Coefficients:

R15: K=-2.99695e+00 B= 2.31988e-02 C=-1.67619e-03

D=-5.45254e-04 E= 6.77550e-04 F=-1.69552e-04

R16: K=-7.75069e+00 B= 6.76237e-03 C= 1.45357e-04

D= 6.41149e-04 E=-2.21028e-04 F=-2.54219e-05

Numerical Example 3:

f= 1~19.99 Fno= 1.85~3.52 2ω= 57.5°~3.1°

R 1= 11.418	D 1= 0.32	N 1= 1.846660	ν 1= 23.8
R 2= 6.159	D 2= 1.28	N 2= 1.603112	ν 2= 60.6
R 3= -54.401	D 3= 0.05		
R 4= 5.371	D 4= 0.68	N 3= 1.638539	ν 3= 55.4
R 5= 13.218	D 5= Variable		
R 6= 11.860	D 6= 0.20	N 4= 1.834000	ν 4= 37.2
R 7= 1.266	D 7= 0.58		
R 8= -4.968	D 8= 0.17	N 5= 1.804000	ν 5= 46.6
R 9= 4.967	D 9= 0.15		
R10= 2.681	D10= 0.59	N 6= 1.846660	ν 6= 23.8
R11= -5.821	D11= 0.03		
R12= -4.397	D12= 0.17	N 7= 1.772499	ν 7= 49.6
R13= 8.565	D13= Variable		

R14= Stop	D14= 0.24		
R15*= 2.197	D15= 0.88	N 8= 1.583126	ν 8= 59.4
R16*= -6.237	D16= 0.07		
R17= 3.230	D17= 0.20	N 9= 1.805181	ν 9= 25.4
R18= 1.899	D18= Variable		
R19= 3.521	D19= 0.61	N10= 1.516330	ν10= 64.1
R20= -1.986	D20= 0.17	N11= 1.805181	ν11= 25.4
R21= -3.697	D21= Variable		
R22= ∞	D22= 0.80	N12= 1.516330	ν12= 64.2
R23= ∞			

*) Aspheric Surface

Variable Separation	Focal Length		
	1.00	8.47	19.99
D 5	0.21	4.90	5.79
D13	6.00	1.30	0.41
D18	2.78	1.13	2.90
D21	0.73	2.39	0.61

Aspheric Coefficients:

R15: K=-2.50798e+00 B= 2.04055e-02 C=-2.87508e-03
D=-6.23936e-04 E= 1.08180e-03 F=-2.36535e-04

R16: K=-8.84264e+00 B= 6.94108e-03 C=-3.62483e-03
D= 1.84163e-03 E=-1.00394e-05 F=-9.76033e-05

Table-1

Condition No. & Factor	Numerical Example		
	1	2	3
(1) $\lvert f2/fA \rvert$	0.27	0.27	0.30
(2) νn	42.2	42.2	44.4
(3) νp	23.8	23.8	23.8
(4) Nn	1.82	1.82	1.80
(5) $\lvert R22/f2 \rvert$	0.97	0.92	0.95
(6) $\lvert R24/R25 \rvert$	2.78	3.63	1.85
(7) $\lvert R26/R27 \rvert$	1.23	1.12	1.32
(8) $\lvert f3/fA \rvert$	0.97	0.96	0.99
(9) $\beta 4T$	0.50	0.50	0.50

It will be appreciated from the foregoing that, according to the first embodiment, the bulk and size of the entire lens system are minimized and, despite the very high zoom ratio and as fast a speed as about 1.6 in F-number, a high optical performance is obtained. Such a zoom lens is achieved by using a smaller number of constituent lenses than was heretofore usual. Further, an excellent optical apparatus using the zoom lens can be realized.

Another or second embodiment of the present invention is described in detail by reference to the drawings below.

Figs. 13, 15 and 17 in block diagram show numerical examples 4 to 6 of the zoom lens according to

the second embodiment. Figs. 14A1 to 14A4, 14B1 to 14B4 and 14C1 to 14C4, Figs. 16A1 to 16A4, 16B1 to 16B4 and 16C1 to 16C4 and Figs. 18A1 to 18A4, 18B1 to 18B4 and 18C1 to 18C4 show the aberrations of the zoom lenses of numerical examples 4 to 6, respectively, in three different operative positions. Figs. 14A1 to 14A4, 16A1 to 16A4 and 18A1 to 18A4 show the aberrations ~~in~~ at the wide-angle end, Figs. 14B1 to 14B4, 16B1 to 16B4 and 18B1 to 18B4 show the aberrations ~~in~~ at a middle focal length position, and Figs. 14C1 to 14C4, 16C1 to 16C4 and 18C1 to 18C4 show the aberrations ~~in~~ at the telephoto end. In the aberration curves, d and g stand for the spectral d- and g-lines, respectively, and ΔM and ΔS stand for the meridional and sagittal image surfaces, respectively. The lateral chromatic aberration is expressed by the g-line.

In the lens block diagrams of Figs. 13, 15 and 17, reference numerals 1 to 4 denote the first to fourth lens units, respectively, SP stands for the stop, P stands for a glass block such as the face plate of the CCD and an optical low-pass filter, and IP stands for the image plane. In the numerical examples 4 to 6, during zooming from the wide-angle end to the telephoto end, as indicated by the arrows in Figs. 13, 15 and 17, the second lens unit 2 axially moves toward the image side, while the fourth lens unit 4 axially moves to compensate for the shift of the image plane with variation of the focal length. The first lens unit 1, the third lens unit

3 and the stop SP remain stationary during zooming.

The locus of zooming movement of the fourth lens unit 4 differs with different object distances. The locus shown by the solid line in Figs. 13, 15 and 17 is for an infinitely distant object, and the locus shown by the dashed line is for an object at the minimum distance. That is, the zoom lenses of the numerical examples 4 to 6 employ the rear-focus method in which the fourth lens unit is axially moved for focusing.

Now, the most characteristic features in the second embodiment are that the second lens unit 2 is constructed with three negative lenses and one positive lens, totaling four single lenses, and further that, among the lenses constituting the second lens unit 2, at least one lens is made aspherical.

In more detail, for the zoom lens of the type as in the second embodiment, if the second lens unit 2 that contributes to a large variation of the focal length is made up in such a way as described above, the share of the power each lens unit should take can be decrease to assure reduction of the Petzval sum. By this, even if the zoom ratio is made high, the variation of field curvature with zooming can be lessened. Further, the use of one or more aspheric surfaces in the second lens unit 2 can assure an increase of the level of optical performance, too. In the numerical examples 4 to 6, the front surface of the positive lens in the second lens unit is aspherical.

The features described above suffice for achieving the second embodiment. To further improve the aberration correction, it is desired that the second lens unit 2 is constructed as comprising, in order from an object side to an image side, a negative first lens having a concave surface of larger curvature facing the image side than that of an opposite surface thereof, a bi-concave negative second lens, a positive third lens having a convex surface of larger curvature facing the object side than that of an opposite surface thereof and a bi-concave negative fourth lens.

With the use of the zoom type as in the first embodiment, in order to increase the zoom ratio, the second lens unit 2 that contributes greatly to the function of varying the focal length must be necessarily made either larger in the total zooming movement, or shorter in focal length. The former method is unfavorable because it increases the size of the zoom lens. The latter method, although not causing the size to increase, puts a large strain on the second lens unit 2, causing good stability of the optical performance to be hardly maintained. Taking these into account, the second lens unit L2 is made up in such a manner as described above. By this, the size of the entire lens system is prevented from increasing, and the optical performance, too, is maintained ~~to~~ with good stability. Particularly, as far as the second lens unit L2 is concerned, the power arrangement is made nearly

symmetrical. In other words, the negative lens, the negative lens, the positive lens and the negative lens are arranged in this order from the object side, thereby correcting chromatic aberrations well. That is, the achromatism of the principal point is effected well. In addition, the aspheric surface is used to improve the off-axial optical performance.

Furthermore, the aspheric surface in the second lens unit takes its place in the positive third lens. With this arrangement, it becomes possible to correct aberrations more effectively. Particularly, the off-axial flare can be corrected well. For this purpose, it is desired to form the aspheric surface to such a shape that the positive refractive power becomes progressively weaker toward the marginal zone of the lens.

Also, letting the focal lengths ~~in~~ at the wide-angle end and the telephoto end of the entire lens system be denoted by fw and ft, respectively, the focal length f2 of the second lens unit is desired to fall within the following range:

$$0.25 < |f2/fA| < 0.41 \quad \ldots (10)$$

where $fA = \sqrt{fw \cdot ft}$.

The above condition (10) is a condition for making appropriate the focal length (in other words, refractive power) of the second lens unit. When the upper limit of the condition (10) is exceeded, as this means that the focal length of the second lens unit is

too long, the aberrations are favorably corrected, but the total zooming movement of the second lens unit must be increased to obtain the desired zoom ratio, causing the size of the entire lens system to increase objectionably. Conversely, when the lower limit is exceeded, the Petzval sum increases in the negative direction, causing the image plane to decline. So, it becomes difficult to keep hold of good optical performance.

Also, the mean Abbe number νp of materials of positive lens in the second lens unit and the mean Abbe number νn of materials of negative lenses in the second lens unit are desired to fall within the respective following ranges:

$$36 < \nu n < 65 \quad \ldots (11)$$

$$20 < \nu p < 35 \quad \ldots (12)$$

The above inequalities of conditions (11) and (12) have an aim to correct well the chromatic aberrations the second lens unit produces. As mentioned in the foregoing, the second lens unit contributes to a large variation of the focal length. Therefore, the aberrations the second lens unit produces must be corrected well. Particularly for the zoom lens of as high a range as exceeding 20, it is of importance that chromatic aberrations, too, be corrected well. When the upper limit of the condition (11) is exceeded, over-correction of longitudinal chromatic aberration results. Conversely, when the lower limit is exceeded,

under-correction of longitudinal chromatic aberration results. Under ~~In the~~ condition (12), the phenomena to occur are reversed to those of the condition (11). However, it is still valid that, when the upper or lower limit is exceeded, the chromatic aberrations are hardly corrected well.

To further improve the aberration correction, the mean refractive index Nn of materials of negative lenses in the second lens unit is desired to fall within the following range:

$$1.71 < Nn < 1.95 \quad \ldots (13)$$

The above condition (13), which correlates with the condition (10), is a condition for preventing the Petzval sum from deteriorating, by using high-refractive-index glasses in the negative lenses. When the limits are exceeded, the curvature of field ~~comes to~~ deteriorates.

Letting the radius of curvature of the i-th lens surface, when counted from the object side, in the second lens unit be denoted by R2i, it is also preferable to satisfy at least one of the following conditions:

$$0.79 < |R22/f2| < 1.32 \quad \ldots (14)$$

$$1.28 < |R24/R25| < 3.20 \quad \ldots (15)$$

$$0.98 < |R26/R27| < 3.55 \quad \ldots (16)$$

The above conditions (14) to (16) have an aim to correct spherical aberration, coma, astigmatism and field curvature in good balance.

When the upper limit of the condition (14) is

exceeded, large coma is produced. Conversely. when the lower limit is exceeded, the image plane is curved concave toward the object side. So, these violations are objectionable.

The condition (15) is a condition for correcting the various aberrations by cancellation between each other's surfaces. When the upper limit of the condition (15) is exceeded, under-correction of spherical aberration results. So, the violation is objectionable. Conversely, when the lower limit is exceeded, the inward coma increases objectionably.

When the upper limit of condition (16) is exceeded, spherical aberration is objectionably over-corrected. Conversely, when the lower limit is exceeded, barrel-type distortion ~~in~~ at the wide-angle end increases objectionably.

On the conditions (14) to (16), satisfaction of any one of the conditions gives the respective individual effect and result. However, needless to say here, simultaneous satisfaction of all the conditions is desired from the viewpoint of the aberration correction.

The data for the numerical examples 4 to 6 of the second embodiment are described below.

Also, the values of the factors in the above-described conditions (10) to (16) for the numerical examples 4 to 6 are listed in Table-2.

Numerical Example 4:

f= 1~20.09 Fno= 1.45~3.80 2ω= 57.5°~3.1°

R 1= 11.602	D 1= 0.30	N 1= 1.846660	ν 1= 23.8
R 2= 5.983	D 2= 1.13	N 2= 1.603112	ν 2= 60.6
R 3= -65.031	D 3= 0.05		
R 4= 5.350	D 4= 0.63	N 3= 1.696797	ν 3= 55.5
R 5= 13.654	D 5= Variable		
R 6= 9.563	D 6= 0.20	N 4= 1.834807	ν 4= 42.7
R 7= 1.419	D 7= 0.57		
R 8= -7.401	D 8= 0.17	N 5= 1.834000	ν 5= 37.2
R 9= 3.555	D 9= 0.12		
R10*= 2.506	D10= 0.66	N 6= 1.846660	ν 6= 23.8
R11= -4.170	D11= 0.05		
R12= -3.062	D12= 0.17	N 7= 1.882997	ν 7= 40.8
R13= 12.531	D13= Variable		
R14= (Stop)	D14= 0.24		
R15*= 4.296	D15= 0.83	N 8= 1.583126	ν 8= 59.4
R16= -4.552	D16= 0.17	N 9= 1.846660	ν 9= 23.8
R17= -6.489	D17= Variable		
R18= 3.016	D18= 0.17	N19= 1.805181	ν10= 25.4
R19= 1.615	D19= 0.83	N11= 1.583126	ν11= 59.4
R20= -7.510	D20= Variable		
R21*= ∞	D21= 0.80	N12= 1.516330	ν12= 64.2
R22= ∞			

*) Aspheric Surface

Variable Separation	Focal Length		
	1.00	6.64	20.09
D 5	0.13	4.33	5.52
D13	5.68	1.48	0.29
D17	2.75	1.46	3.58
D20	1.22	2.51	0.39

Aspheric Coefficients:

R10: K= 2.26914e-02 B=-3.85620e-04 C= 1.31875e-04

D= 5.87667e-05 E=-7.29183e-04

R15: K=-8.90748e-01 B=-3.94769e-03 C= 4.25368e-04

D=-1.77499e-04 E= 3.13494e-05

R20: K=-1.22783e+01 B=-2.03783e-03 C= 2.76322e-03

D=-3.99845e-03 E= 3.24721e-03 F=-1.41807e-03

Numerical Example 5:

f= 1~20.00 Fno= 1.89~3.18 2ω= 57.5°~3.1°

R 1= 13.233	D 1= 0.34	N 1= 1.846660	ν 1= 23.8
R 2= 7.170	D 2= 1.27	N 2= 1.603112	ν 2= 60.6
R 3= -105.995	D 3= 0.05		
R 4= 6.330	D 4= 0.68	N 3= 1.696797	ν 3= 55.5
R 5= 14.095	D 5= Variable		
R 6= 7.072	D 6= 0.20	N 4= 1.834807	ν 4= 42.7
R 7= 1.465	D 7= 0.80		
R 8= -30.695	D 8= 0.17	N 5= 1.834000	ν 5= 37.2
R 9= 6.535	D 9= 0.07		
R10*= 2.273	D10= 0.68	N 6= 1.846660	ν 6= 23.8

R11= -20.040	D11= 0.06		
R12= -6.212	D12= 0.17	N 7= 1.882997	ν 7= 40.8
R13= 4.029	D13= Variable		
R14= (Stop)	D14= 0.24		
R15*= 7.266	D15= 0.42	N 8= 1.589130	ν 8= 61.1
R16*= -6.822	D16= Variable		
R17= 3.832	D17= 0.20	N 9= 1.805181	ν 9= 25.4
R18= 1.708	D18= 0.73	N10= 1.622992	ν10= 58.2
R19= -5.692	D19= Variable		
R20= ∞	D20= 0.80	N11= 1.516330	ν11= 64.2
R21= ∞			

*) Aspheric Surface

Variable Separation	Focal Length		
	1.00	7.34	20.00
D 5	0.17	5.43	6.91
D13	7.07	1.81	0.33
D16	2.51	1.24	2.95
D19	1.22	2.50	0.78

Aspheric Coefficients:

R10: K= 1.70649e-01 B= 6.91700e-05 C= 3.75749e-04
D=-1.12207e-03 E= 3.99870e-04 F= 3.59130e-04

R15: K=-2.43481e+00 B=-1.30559e-02 C=-1.05458e-03
D=-4.16775e-03 E=-1.22870e-05

R20: K= 2.53727e-01 B=-8.97451e-03 C=-1.43273e-03
D=-3.76794e-03 E=-9.23858e-04 F= 2.32567e-06

Numerical Example 6:

f= 1~20.01 Fno= 1.85~3.57 2ω= 57.5°~3 1°

R 1= 11.768	D 1= 0.32	N 1= 1.846660	ν 1= 23.8
R 2= 6.152	D 2= 1.28	N 2= 1.603112	ν 2= 60.6
R 3= -36.138	D 3= 0.05		
R 4= 5.155	D 4= 0.68	N 3= 1.638539	ν 3= 55.4
R 5= 12.283	D 5= Variable		
R 6= 11.941	D 6= 0.20	N 4= 1.834000	ν 4= 37.2
R 7= 1.326	D 7= 0.58		
R 8= -2.951	D 8= 0.17	N 5= 1.804000	ν 5= 46.6
R 9= 7.313	D 9= 0.15		
R10*= 2.515	D10= 0.59	N 6= 1.846660	ν 6= 23.8
R11= -5.746	D11= 0.03		
R12= -5 251	D12= 0.17	N 7= 1.772499	ν 7= 49.6
R13= 5.609	D13= Variable		
R14= (Stop)	D14= 0.24		
R15*= 1.988	D15= 0.88	N 8= 1.583126	ν 8= 59.4
R16*= -6.724	D16= 0.07		
R17= 3.021	D17= 0.20	N 9= 1.805181	ν 9= 25.4
R18= 1.756	D18= Variable		
R19= 2.963	D19= 0.61	N10= 1.516330	ν10= 64.1
R20= -1.935	D20= 0.17	N11= 1.805181	ν11= 25.4
R21= -4.000	D21= Variable		
R22= ∞	D22= 0.80	N12= 1.516330	ν12= 64.2
R23= ∞			

*) Aspheric Surface

Variable Separation	Focal Length		
	1.00	6.57	20.01
D 5	0.21	4.35	5.51
D13	5.68	1.54	0.37
D18	2.82	1.12	2.94
D21	0.73	2.43	0.61

Aspheric Coefficients:

R10: K=-1.09373e+00 B=-2.56364e-03 C= 3.87936e-03
D=-7.39355e-04 E=-5.96622e-03 F= 3.58603e-03

R15: K=-2.19525e+00 B= 2.43661e-02 C=-3.38432e-03
D=-7.29503e-04 E= 1.50629e-03 F=-2.62456e-04

R20: K=-2.53128e+01 B= 4.68360e-03 C=-3.67596e-03
D= 2.50751e-03 E=-4.68734e-06 F=-4.93152e-05

Table-2

Condition No.	Numerical Example		
	4	5	6
(10)	0.31	0.37	0.28
(11)	40.2	40.2	44.4
(12)	23.8	23.8	23.8
(13)	1.85	1.85	1.80
(14)	1.20	0.88	1.05
(15)	1.42	2.88	2.91
(16)	1.36	3.23	1.09

It will be appreciated from the foregoing that, according to the second embodiment, the bulk and size of the entire lens system are minimized and, despite the very high zoom ratio, while still increasing the speed to about 1.4 in F-number, a high level of optical performance is obtained. Such a zoom lens is made possible ~~to realize~~ by using a smaller number of constituent lenses than was heretofore usual.

Next, a practical example of a video camera using any one of the zoom lenses of numerical examples 1 to 6 as the photographic optical system is described by reference to Fig. 19.

In Fig. 19, the video camera has a body 10 in which a photographic optical system 11 in the form of the zoom lens of each of the numerical examples 1 to 6 is incorporated. By the photographic optical system 11, an image of an object being photographed is formed on an image pickup element 12, such as CCD. An electrical signal representing the object image is transferred from the image pickup element 12 to, and stored in, a recording medium 13. The photographer, looking through a viewfinder 14, observes an object image on a display (not shown). The display is formed by a liquid crystal panel on which an equivalent image to that on the image pickup element 12 appears.

In such a manner, the zoom lens of each of the numerical examples 1 to 6 is applied to the video camera or like optical apparatus. An optical apparatus of

reduced size with high optical performance can thus be realized.